The influence of leads on cognitive load and learning in a hypertext environment

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A B S T R A C T

The purpose of this study was to determine the effect of leads (or hypertext node previews) on cognitive load and learning. Leads provided a brief summary of information in the linked node, which helped orient the reader to the linked information. Dependent variables included measures of cognitive load: self-report of mental effort, reading time, and event-related desynchronization percentage of alpha, beta and theta brain wave rhythms; and learning performance: a recall task, and tests of domain and structural knowledge. Results indicated that use of leads reduced brain wave activity that may reflect split attention and extraneous cognitive load, and improved domain and structural knowledge acquisition. Further, findings provide insights into differentiating the types of cognitive load apparent in hypertext-assisted learning environments. Use of EEG measures allowed examination of instantaneous cognitive load, which showed that leads may be influencing germane load—reducing mental burden associated with creating coherence between two linked node. The self-report of mental effort measure appears more closely associated with overall and intrinsic load.

1. Introduction

Hypertext systems, like the World Wide Web, provide a linked computer-based information storage and retrieval system, in which massive amounts of information are organized into a vast semantic network (Rada, 1989). Since its very inception, psychologists and educators have been enthusiastic about the potential of hypertext to serve as an intellectual partner for the reader (e.g., Jonassen, 2000), thereby enriching the learning experience. The unique characteristics of hypertext provide a mechanism for elaborating topics via hyperlinks, leading researchers to believe that this format of text presentation requires learners to take a more active approach to reading by interacting more directly with the content (Landow, 1992), enhances conceptual and structural knowledge acquisition (Jonassen & Wang, 1993), and results in more flexible knowledge representations that enhance transfer of learning (Spiro, Vispoel, Schmitz, Samarapungavan, & Boerger, 1987). However, despite initial hopes that using hypertext would enhance learning, little empirical evidence exists to supports these claims, and the cognitive consequences of hypertext-assisted learning continue to be debated (Calandra & Barron, 2005; DeStefano & LeFevre, 2007).

2. Theoretical framework

Reading hypertext is a task of exploration. Unlike print text, that is typically read in a sequence prescribed by the author, hypertext is presented in brief nodes that contain one or more concise expository paragraphs, for which the reader determines access sequence. Each node must be self-contained because hypertext authors cannot make assumptions about which nodes have already been read. The unique characteristics of hypertext allow hypertext authors to create connections to other related topics that are not easily accomplished in traditional print text presentation. Hyperlinks form a more intricate web of connected information nodes than is permitted by the straight-forward flow of a print text, even texts with elaborate annotations and footnotes. Thus, hypertext readers can determine their own path through the content, supporting creation of their own unique knowledge representations by selecting among the various linked concepts presented in hypertext nodes (Rouet, Levonen, Dillon, & Spiro, 1996).

2.1. Role of cognitive load in reading hypertext

Both traditional print text and hypertext provide contexts for learning and organizing complex conceptual information. Processing print text and hypertext occurs on many levels, from low-level processes like decoding characters, recognizing words, and parsing sentences; to higher-level comprehension processes through which readers develop a situation model of the content by
integrating new information into their existing knowledge base (Niederhauser, 2008; Shapiro & Niederhauser, 2004; Alexander, Kulikowich & Jetton, 1994). In addition to cognitive processes, reading involves metacognitive activity. Skilled readers continuously monitor comprehension to identify possible information gaps in their situation model (Azevedo & Jacobson, 2008), and selectively allocate attentional resources based on perceived importance and relevance of information (Reynolds, 2000).

While learning from print text and hypertext is grounded in the same basic reading processes, making meaning in a hypertext-assisted learning environment places additional cognitive demands on the reader (Niederhauser, Reynolds, Salmen, & Skolmoski, 2000). After reading a given node, hypertext readers must actively decide which informational node to read next, given their interests and learning goals on one hand, and the potential relational-linking options provided by the interface links on the other (Landow, 1992). Through this process of selecting nodes and monitoring comprehension, readers engage in cognitive activity to integrate concepts from spatially distinct nodes (DeStefano & Lefevre, 2007), and metacognitive activity to consider various paths available to them, and choose some paths over others (Charney, 1994). The additional cognitive and metacognitive processes involved in navigating and making meaning from linked hypertext nodes appears to increase cognitive demands on the reader.

For example, in a hypertext study that was grounded in cognitive flexibility theory (see Spiro, Coulson, Feltovich & Anderson, 1988), Niederhauser et al. (2000) hypothesized that students who took advantage of compare and contrast links within a large hierarchical hypertext on behaviorism and constructivism would develop a deeper, more integrated understanding of this complex domain than would those who chose to sequentially read through all of the information on one learning theory, then read the information in the second theory in the same manner. Unexpectedly, results indicated that learners who used links to compare and contrast concepts tended to have lower scores on learning measures than did those who employed a more sequential approach characteristic of reading traditional print text. The latter group adopted a strategy for choosing which node to read next that minimized their use of cognitive resources associated with constructing an individualized path through the text. The authors concluded that the benefits these students might have gained by engaging in deeper processing to compare and contrast the content may have been mitigated by increased cognitive load (see Sweller, 1989, 1994) associated with navigating the hypertext. Consistent with these results, other researchers have reported better factual recall from reading linear texts when compared to hypertexts (Barab, Young, & Wang, 1999; Eveland, Cortese, Park, & Dunwoody, 2004). Similarily, Zhu (1999) demonstrated that learning performance on a multiple-choice test and written summary, as well as subjective ratings of the hypertext system, were better when linking options were limited to 3–7 links, when compared to a comparable system containing 8–12 links. Cognitive load theory offers a useful framework to interpret these findings.

Cognitive load refers to the mental burden that performing a task imposes on the learner (Sweller, 1988). Three types of cognitive load have been identified in the literature (Sweller, van Merrienboer, & Paas, 1998). Intrinsic load is imposed by the inherent complexity of the content, which relates to the extent to which various information elements interact. When information interactivity is low, content can be understood and learned one element at a time. Conversely, highly interactive information is more difficult to learn. For example, learning individual words of a foreign language is intrinsically less demanding than learning grammar because, while vocabulary can be learned word-by-word, learning to construct a sentence requires understanding of both the words that make up the sentence, and the rules that govern things like word order and tense agreement.

While intrinsic load is generally thought to be immutable to instructional manipulations due to the inherent complexity of content (Sweller et al., 1998), learning difficulty can be manipulated by controlling the contributions of germane and extraneous load. Unlike intrinsic load, which is caused by the number of interacting information elements and the extent to which these elements interact, germane load is mediated by the learner’s prior knowledge of the domain, cognitive and metacognitive skills, and, therefore, depends on the individual differences and learning characteristics of each individual learner. Learners experience germane load, when learning activities and/or materials encourage higher-order thinking and challenge the learner at an appropriate level—within what Vygotsky (1978) called their zone of proximal development. In hypertext-based learning materials, a potential source of germane load is the cognitive flexibility that is involved in the development of a situation model of the content. According to Spiro et al. (1988), this criss-crossing of the conceptual landscape allows learners to achieve deeper, more connected understandings as they arrive at informational nodes from various intellectual perspectives. Each user-control decision about whether to follow a hyperlink requires cognitive resource investment and creates germane load when making this decision activates learners’ prior knowledge of the domain and engages them in deeper semantic processing that encourages restructuring and expanding one’s knowledge base (Niederhauser et al., 2000).

Although germane load is necessary for learning, managing its levels is critical to effective instructional design. When learning activities or materials are not cognitively challenging for the learner, germane load is low, which may result in a decrease in interest and learning. Conversely, content that is so challenging for the learner that it lies beyond his or her zone of proximal development may cause inappropriately high levels of germane cognitive load, which may also impair learning. Thus, germane load can be managed through selection of tasks and content that is of appropriate difficulty for the learner.

Cognitive investment that does not contribute to (or interferes with) understanding of the content to-be-learned is termed extraneous load (Chandler & Sweller, 1992). Potential extraneous load may be present at several levels in the context of hypertext-assisted learning. Since learning from hypertext involves reading, extraneous load associated with basic reading processes like decoding, comprehension monitoring, and situation model development have cognitive consequences for learning. Further, as with any computer-based information presentation system, extraneous load may occur when readers lack facility with computers or familiarity with the program, and they must invest cognitive resources to figure out the basic operation of the computer and software, which, in the case of hypertext, involves actions like navigating links, menus, and lists. Negative effects of extraneous load associated with navigating a hypertext can result in a sense of disorientation (Dias & Sousa, 1997; Kim & Hirtle, 1995) and finding oneself to be “lost in hyperspace” (Otter & Johnson, 2000; Shapiro & Niederhauser, 2004).

Intrinsic, germane, and extraneous load are additive (Paas, Tuovinen, Tabbers, & van Gerven, 2003), and if the sum of the various loads exceeds the learner’s cognitive capacity, learning will be impaired. Since intrinsic load is thought to be immutable and germane load is necessary for learning, managing cognitive load in instructional settings involves selecting content that is appropriately challenging for the learner, and structuring the learning environment to reduce extraneous load—thereby freeing cognitive capacity to allow a greater proportion of germane load to be used for deeper processing of the information.
2.2. Working memory limitations and split attention in hypertext reading

Dynamics of cognitive load are directly influenced by the characteristics of human cognitive architecture (Sweller, 2008). In particular, the limited capacity of working memory may create challenges for hypertext readers. With print text the author typically tries to present a series of logical internally consistent points in the text in an effort to conceptually guide the reader. Reading linked information in hypertext, however, requires the reader to assume responsibility for developing a coherent representation of the textbase. It is up to the reader to develop a coherent understanding of the content by integrating information from the text with prior knowledge, and creating a more sophisticated situation model. To accomplish this integration, the reader must hold conceptual representations encountered in a given node in working memory while considering how the information from a new node might relate. The reader must then decide what to read next among the available links, and select a new node that will, in the reader’s opinion, lead to additional promising information. This process continues until the information is rendered sensible and the reader’s situation model of the text has been created.

A fundamental problem with processing information in this manner lies in the fact that human cognitive architecture constrains readers’ ability to optimally integrate concepts from working memory into long-term memory when reading is interrupted (Glanzer, Fischer, & Dorfman, 1984). For each disruption, critical text information must be reinstated in working memory if the reader is to successfully continue the situation model building process. When learning from hypertext, situation model development is continually disrupted because information is presented in separate nodes, leading to attentional division between concepts from the current node being held in working memory, and the novel information encountered in a new node. This split attention effect clearly has implications for hypertext-assisted learning.

The debate on whether it is possible to attend to multiple sources of information at once has been of interest to psychologists since the 1890s (Benjamin, 1968). Cognitive psychologists have suggested that split attention is caused by intensive search-and-match processes involved in cross-referencing units of information in working memory (Chandler & Sweller, 1992). Additional cognitive processing associated with split attention may function as a source of extraneous load on limited working memory resources, resulting in acquisition of knowledge fragments instead of coherent knowledge structures (Kalyuga, Ayres, Chandler, & Sweller, 2003).

Physical integration of related information elements has been proposed as a means to address extraneous load associated with the split attention problem (Chandler & Sweller, 1992; Mayer & Anderson, 1991). Taken to an extreme, this would involve the elimination of links to allow spatial integration of the hypertext nodes into one undivided unit—essentially making it a scrolling print text. While this might solve the hypertext linking split attention problem, efforts to reduce extraneous load by using a linear “linkless” format removes the opportunity to enhance germane load that is afforded in a hypertext environment. The comparison and elaboration processes that facilitate complex situation model construction and automation of flexible, adaptive schemas represented in the cognitive flexibility viewpoint are less likely to occur when reading sequential text. Thus, such conversion would eradicate the primary advantage of hypertext (a flexible access information structure) relative to key aspects of both cognitive flexibility theory and cognitive load theory.

In an effort to make hypertext-assisted learning environments more comprehensible, designers of hypertext-based learning materials have proposed learner-support tools like guided tours, hierarchies, outlines, and graphical overviews, which have been used with varying success across different types of learners and content areas (Boechler & Dawson, 2002). Researchers have also proposed guidelines for developers to help learners recognize the relationships among ideas scattered across a hypertext (e.g., McNamara & Shapiro, 2005; Shapiro, 2008). Although using these guidelines may help learners develop an overview of the scope and sequence of the hypertext, these efforts are focused on reducing extraneous load at the global organizational level, providing little support for split attention effects that take place locally—when linking between individual hypertext nodes. However, navigational decisions are made, and potential situations for split attention occur, when the reader is selecting an embedded link (or hotword) to a new node. In many cases these hotwords are the primary navigation method available in a hypertext system, and since they provide little contextual support, there appears to be a need to provide additional structural cues that address split attention, reduce extraneous load, and support textbase construction in hypertext-assisted learning environments.

2.3. Leads

One mechanism that may reduce split attention and help learners develop better situation models from hypertext is a lead. Initially devised by journalists to provide readers with a preview of a newspaper article, leads may function as what Ausubel (1960) referred to as an advance organizer. An advance organizer is “introduc- tory material at a higher level of abstraction, generality, and inclusiveness than the learning passage itself” (Ausubel, 1978, p.252). Ausubel’s original research (and many studies thereafter) studied the use of textual organizers on verbal learning. Ausubel (1960) asked college students to read a 2500-word passage about metallurgy after reading either a 500-word advance organizer that presented the underlying concepts or a 500-word historical passage. The advance organizer group performed better on a subsequent test of retention, presumably because the learners were able to tie the information to knowledge structures presented in the organizer. Mayer (1979) reviewed 27 empirical studies that compared an advance organizer group with a control group, and found a small but consistent advantage for the advance organizer participants on tests of retention and learning. This advantage was more likely when: (a) the content was unfamiliar and (b) the learners were less experienced in the subject matter.

With respect to hypertext, advance organizers like leads may serve to orient and prepare the reader for information contained in the linked node while the current node is still visible. Leads may be implemented in the form of a mouse-over balloon that pops up next to the relevant hotword link. Thus, in a lead-augmented hypertext system, the reader has the opportunity to get an idea of what is coming in the next node without having to leave the current node.

While the idea of using leads may be relatively new in educational hypertexts, there is evidence that demonstrates their potential value. Empirical research has shown the value of link comments (which are conceptually equivalent to leads) in several areas. For example, they have proven useful in hypertext-assisted learning by improving appropriateness of link selection during a browsing session (Schweiger, 2001), helping readers integrate textual and pictorial information (Betrancourt & Biseret, 1998), by enhancing searching and knowledge acquisition (Cress & Knabel, 2003), and supporting navigational decisions (Maes, van Geel, & Cozijn, 2006). Although this research has furthered our understanding of the potential role of leads in enhancing some aspects of hypertext-assisted learning, we know little about the effects of leads on helping learners overcome split attention, optimizing cognitive load, and improving learning outcomes.
The present study was designed to examine the effect of leads on extraneous cognitive load associated with split attention, and subsequent effects on learning in a conceptually rich hypertext environment. Subjective, behavioral, and psychophysiological methods, including self-reported mental effort, reading time, and electroencephalogram, were employed to assess cognitive load while participants read traditional and lead-augmented hypertext. Subjects’ learning performance in the two experimental conditions was assessed and compared based on measures of recall, domain, and structural knowledge. This research was driven by the following research questions:

1. What are the effects of leads on cognitive load in a hypertext-assisted learning environment?
2. To what extent does the use of leads influence learning performance?

3. Method

3.1. Subjects

The initial subject pool included 22 teacher education students from a large Midwestern university. An invitation to participate was e-mailed to all undergraduate education majors (n = 687). Fifteen dollars and an opportunity to win an iPod Nano™ served as incentives. The first 22 respondents who met the study criteria were enrolled as subjects in the study; however, two subjects did not complete one or more of the experimental tasks and were dropped from the study, yielding a final subject pool of 20 participants. Because EEG studies of brain wave patterns are conducted in the within-subject format, where each subject as his or her own control (Pivik et al., 1993), the sample size is typically limited to about 10 participants, with the average being 13 (e.g., Gevins et al., 1998; Kaiser, 1994).

Subject selection was used to help control for some of the variance associated with interpersonal differences. Researchers have suggested that gender, handedness, and age can differentially affect brain wave activity (Andreassi, 2007; Fisch, 1999). Further, EEG patterns can be influenced by brain disorders, or medications to treat brain disorder conditions (Andreassi, 2007). Thus, the subject pool was limited to right-handed, 18–23 year-old females with no known brain disorders.

Based on an initial demographic questionnaire, all subjects described themselves as native English speakers and experienced computer and hypertext users. Ten subjects were raised in a family with low to medium income ($30,000–$60,000), while the remainder came from more affluent families (above $60,000). The sample consisted of ten seniors, three juniors, two sophomores, and five freshmen. Most (n = 11) were majoring in Elementary Education. Of the remainder, five were in Early Childhood Education, two in secondary Mathematics, one in secondary Biology, and one in Family and Consumer Science. All subjects characterized themselves as novices with regard to the learning theories presented in the instructional materials, even though 13 of them had taken an introductory educational psychology course. Seven subjects indicated that they preferred reading websites to reading books. Eleven reported taking courses, which required them to read text from websites at least once a week, seven reported reading course information from websites occasionally, and two indicated they always printed web-based materials before reading them.

3.2. Materials

Materials for the study included four hypertexts, each on a different learning theory, a hypertext presentation system, and measures to assess reading ability, metacognitive awareness, prior knowledge, cognitive load, and learning performance.

3.2.1. Learning theory hypertexts

Four instructional hypertexts were developed to present background information on each of four learning theories: Behaviorism, Information Processing, Cognitive Constructivism, and Social Constructivism. Structure was consistent with what is referred to as “schema-driven design” (Lawless & Brown, 1997). Each text included a primary passage and seven linked nodes. The primary passages contained seven links to subordinate nodes describing the theory’s social context, an influential theorist, the view of knowledge inherent in the theory, and other defining concepts. Nodes contained 90 ± 5 words.

Information Processing and Cognitive Constructivism hypertexts were augmented with leads. Hypertexts on Social Constructivism and Behaviorism did not contain leads. Leads included 10 ± 2 words. To reduce potential text-driven interactions in this study, experimental texts were normalized and compared by a linguist and four educational psychology experts. All texts were measured and adjusted to have equivalent Flesch reading ease scores of 35, which is considered an appropriate difficulty level for high school and college students (Flesch, 1948). Conceptual difficulty equivalence and content validity were established through a read-and-revisit process by four educational psychology experts and a linguist who reviewed and corrected the texts to ensure that (a) the same number of concepts (n = 7) were covered in the linked nodes of each text, (b) the concepts were of the same level of domain-specificity (e.g., influential scholar, view of knowledge), and (c) identical grammatical and syntactical structures were used across all texts (e.g., sentence length, number of clauses, stylistic devices).

3.2.2. Hypertext presentation system

The hypertext presentation system was designed using guidelines suggested by current web usability research (Nielsen, 2003). Nodes were presented as a single frame using Georgia serif font, with black lettering on a white background and no tracing images or watermarks. Font size was set to 100 percent of the default browser font size, which translated to approximately 16 point font on the monitor used for the study. Three styles were used to identify links to subordinate nodes: (a) blue, underlined for all new, non-active links; (b) purple, underlined for all visited, non-active links; and (c) red, underlined for active links. Both primary passages and subordinate nodes included a banner indicating the name of the learning theory, and the informational text in the body of the frame. A sample primary passage, with rollover lead activated, can be seen in Fig. 1.

Four restrictions were used to guide the development of the hypertext system to avoid contamination from variables other than those of interest in the present study: (a) no images were used to remove variance associated with media other than text; (b) only contextual (embossed hotword) links were available as a navigation method to remove variance associated with different navigational options (e.g., menus, maps, lists etc.); (c) no links to external websites were included to limit access to information; (d) all new nodes opened in the same browser window, so subjects could view only one informational frame at a time.

Leads were implemented as mouse-over popup balloons which introduced the content that would be presented in each of the seven subordinate nodes in the given passage (see Fig. 1). Presentation of leads was based on a mouse-over event (rather than a mouse click). Subjects were able to hover the cursor over the link and read the lead, before deciding whether to click on the link and proceed to the subordinate node. Balloons covered the
remainder of the current line of text and part of the two lines of
text following the link, essentially preventing subjects from contin-
uing to read the text that followed the hotword while the popup
was active. Clicking the hotword accessed the subordinate node
using the same window, and a return link in the subordinate node
took the reader back to the primary passage.

3.3. Measures

3.3.1. Individual difference measures

3.3.1.1. Demographic questionnaire. Subjects completed a 17-item
demographic questionnaire to provide information on major, year
in school, and whether they had taken any classes in educational
psychology. They also provided information on their experience
and confidence in using computers and the Internet, and their hab-
its and preferences associated with reading texts from books or
websites.

3.3.1.2. Hypertext navigation and reading time. Navigation path
and reading time data were recorded using Camtasia™ screen-capture
software. Each time a subject clicked on a link in the traditional
hypertexts—or clicked a link after reading a lead in the lead-aug-
mented hypertexts—a marker was placed on the EEG recording.
Subjects were instructed to read each hypertext at their normal
reading pace, and to keep reading and reviewing until they felt that
they thoroughly understood the content. Total reading time was
computed for each hypertext, and amount of time spent reading
in the lead and no-lead conditions served as the reading time
measure.

3.3.1.3. Reading comprehension. Subjects’ ability to understand
what they read was assessed using the Nelson-Denny advanced
reading comprehension test, Form E (Brown, Bennett, & Hanna,
1981). Subjects read eight passages on various topics and an-
swered a total of 24 five-option multiple-choice questions about
information presented in the passages.

3.3.1.4. Domain knowledge pretest. Prior knowledge of the educa-
tional psychology content was assessed using a four alternative
12-item multiple-choice test—three questions for each of the four
learning theories presented in the hypertext. For example, subjects
were asked:

- How do behaviorists believe we learn?
  a. Associations between stimuli and responses become
     automatic.
  b. Through fear of punishment.
  c. By making sense of experiences.
  d. From trial and error.

3.3.1.5. Metacognitive awareness. Metacognitive awareness was as-
essed using the Metacognitive Awareness Inventory (Schraw &
Dennison, 1994). In this instrument items were classified into
two metacognitive factors—knowledge of cognition and regulation
of cognition. Knowledge of cognition included items like “I know
what kind of information is most important to learn,” and “I am
a good judge of how well I understand something;” while regula-
tion of cognition included items like “I think about what I really
need to learn before I begin a task,” and “I find myself pausing reg-
ularly to check my comprehension.” Subjects responded to the 52
items using a True/False response scale. In a study analyzing use of
comprehension aids in a hypermedia environment with 116 col-
lege students, Cronbach’s alpha for the MAI was estimated at

![Fig. 1. Screenshot of the primary passage of a lead-augmented hypertext system.](image-url)
0.86—indicating acceptable internal consistency (Bendixen & Hartley, 2003).

3.3.2. Cognitive load measures

3.3.2.1. Self-report of mental effort. The subjective measure of self-reported mental effort used in this experiment was a version of the Bratfisch, Borg, and Dornic (1972) scale for measuring perceived task difficulty as modified by Paas (1992). Numerical values and labels assigned to the categories ranged from very, very low mental effort (1) to very, very high mental effort (9). Reliability of the scale in previous research with college students was estimated at 0.90 using Cronbach’s coefficient alpha (Paas & van Merriënboer, 1994). The scale was discussed with the subjects before beginning experimental sessions. Average subject ratings of mental effort for lead-augmented and non-lead-augmented hypertext passages served as the measure of self-report of mental effort.

3.3.2.2. Electroencephalogram. EEG data were acquired using a Biopac MP30 connected to a Macintosh G4 MiniMac computer. Electrode placement was confined to one set of electrodes over the pre-frontal cortex (F7) and one-over the parietal lobe (P3) in the left hemisphere of the right-handed subjects. EEG data were collected at a sampling rate of 500 Hz as each subject read each of the four hypertexts. Electrode placement followed the Modified Combinatorial Nomenclature expanded 10–20 system, as proposed by the American Clinical Neurophysiology Society (Jasper, 1958). The EEG software recorded brain wave rhythms as separate channels, allowing identification of the following wave components: (a) raw EEG signal, (b) alpha rhythm, (c) beta rhythm, and (d) theta rhythm.

Event-Related Desynchronization percentage (ERD%) for alpha, beta, and theta rhythms were used as online measures of brain activity (Pfurtscheller & Lopes de Silva, 1999). Increased cognitive load is associated with higher brain wave desynchronization for alpha and beta rhythms, and higher brain wave synchronization for the theta rhythm, when subjects move from a relaxed, eyes-closed state (baseline) to an eyes-open, active-reading state (Basar, 2004; Klimesch, 2005). Consequently, ERD%, which compares brainwave power in the test condition with the brain wave power in the baseline condition, is represented by a positive number for the subjects’ alpha and beta rhythms (reflecting wave desynchronization), and a negative number for the theta rhythm (reflecting synchronization). Thus, larger desynchronization percent values for alpha and beta waves, and larger synchronization percent values for theta waves indicate increased cognitive load.

The following formula was used to compute ERD% (Pfurtscheller & Lopes de Silva, 1999):

\[
\text{ERD\%} = \frac{\text{baseline interval band power} - \text{test interval band power}}{\text{baseline interval band power}} \times 100
\]

Band power values of the subject’s alpha, beta, and theta brain waves were estimated with the Biopac psychophysiological system software. The Area function was used to calculate alpha, beta, and theta wave power. This function computes the total area of raw EEG signal, (b) alpha rhythm, (c) beta rhythm, and (d) theta rhythm.

3.3.3. Learning measures

3.3.3.1. Recall. Prompted verbal recall was used to assess what students remembered after reading the texts. Each subject was shown a visual prompt containing the name of a learning theory and asked to verbally recount everything she could remember about that text. This procedure was repeated with the remaining text topics, providing an opportunity for subjects to recall information about each theory in the order in which they had been presented. Student responses were digitally recorded and audio files were transcribed. Recall was determined by counting the number of discrete concepts subjects mentioned for each theory. Proportion of concepts recalled served as the recall measure.

3.3.3.2. Structural knowledge. Subjects’ structural knowledge was assessed using a concept-sorting task. Each subject was presented with an Inspiration™ concept-mapping software template containing (a) columns with names of the four learning theories and (b) 28 key concepts (one concept for each of the seven subordinate nodes for each of the four texts) presented in a randomized cluster on the bottom of the screen. Subjects were instructed to drag and drop each of the 28 concepts into the appropriate learning theory column. Proportion of correctly placed concepts served as the structural knowledge measure.

3.3.3.3. Domain knowledge post-test. Domain knowledge was assessed using a multiple-choice test. Twenty-eight new questions (seven per text) were added to the twelve pretest items to create the 40-item four-alternative domain knowledge post-test. Randomly presented items were distributed evenly across the four texts to assess content presented in both primary passages and subordinate nodes. Post-test items were identical to pretest items in form. Proportion of correct responses served as the domain knowledge measure.

3.4. Procedure

3.4.1. Pre-treatment phase

The entire group of subjects attended one initial session as a group before participating in the treatment phase of the study. Those who wore corrective lenses were instructed to wear them
when participating in all research activities. Each subject sat at a desk with a pencil and the reading comprehension measure, domain knowledge pretest, metacognitive awareness inventory, and demographic questionnaire placed on the writing surface in the order in which they were to be completed. A researcher read a prepared script to direct the students through the activities and answered any questions that arose. Each subject then scheduled an individual time to complete the treatment phase during the immediately following 2-week period.

3.4.2. Treatment phase

The treatment phase took place in a 12 by 16 foot physiological testing laboratory. The lab was located in a quiet area removed from hallways and had a heavy door to guard against distracting audio stimuli. All walls were painted white and the ceiling was a white drop-panel design with recessed fluorescent lights. Each lighting fixture contained three bulbs on separate switches. All room lights were on during treatment sessions and no external light was allowed to enter the room. This laboratory setting provided consistent environmental conditions for all subjects.

Subjects participated in the treatment phase one at a time. Each sat at a table with an adjustable-height high-back chair with armrests. Subjects faced a blank white wall, which extended beyond peripheral vision on both sides. A full-size 110-key keyboard, wireless mouse, and 17-inch LCD monitor were on the table in front of the subject. The same computer and monitor were used for all subjects.

The monitor surface was approximately 50 cm from the subject, and was set to 1280 by 854 pixels (the highest available resolution) and maximum level of brightness. Luminance was measured at eye-level and at a distance of approximately 50 cm from the computer screen using a Tenma Digital Lux meter. Luminosity of hypertext displayed on the LCD monitor was equal across text conditions.

With the subject comfortably seated at the computer, the researcher read a scripted verbal overview of treatment procedures to begin the session. He then attached disposable vinyl electrodes (Ag/AgCl) to two recording sites on the subject’s skull: (a) prefrontal lobe (F7) to collect data on the power of beta and theta waves and (b) parietal lobe (P3) to collect data on the power of alpha waves. Measurements were referenced to the left mastoid with the earlobe serving as ground. Electrode impedance was below 10 kΩ. The EEG signal passed through an Infinite Impulse Response (IRI) bandpass filter to remove unintended artifacts of movement, allowing us to retain only the frequency components that were of interest in the present study: theta (4–7 Hz), alpha (8–13 Hz), and beta (14–30 Hz). Two more sets of electrodes were attached to collect the subject’s electrooculogram and electromyogram of the dominant (right) hand, which was used to filter artifacts associated with eye movement, blinking, hand movement and mouse clicking. Subjects were instructed to minimize unnecessary movement during the hypertext reading and browsing task.

After all electrodes were placed and the EEG equipment was activated, the subject sat in a relaxed state with her eyes closed until an extended alpha pattern was noted. At that point the 20-s baseline brain wave rhythm sample was recorded and the subject was instructed to open her eyes (blocking the alpha rhythm) and read the first experimental hypertext. When the subject had finished reading she said “done,” completed a self-report of mental effort measure, and closed her eyes and relaxed until her brainwave patterns returned to the baseline condition (extended alpha). Returning to baseline helped circumvent carryover effects from one treatment to the next.

The researcher brought up the next experimental text while the subject was returning to baseline. After establishing and recording the next baseline brain wave sample, the subject was instructed to open her eyes and read the second text, complete the mental effort scale, and close her eyes until she returned to the baseline condition. This procedure was repeated for the remaining two texts. The sequence of presenting texts to subjects was counterbalanced: lead/no-lead/lead/no-lead for half the subjects, and no-lead/lead/no-lead/lead for the remainder. When a subject had finished reading the fourth hypertext, she was instructed to close her eyes to return to an alpha state, which provided an end point for the brain wave recording.

3.4.3. Post-treatment phase

When the subject had finished reading all four texts, she was asked to complete four “word jumble” anagrams as an interpolated task to clear working memory. Learning performance was then assessed in the following sequence: free recall task, structural knowledge concept-sorting task, and domain knowledge multiple-choice post-test. Subjects were then paid $15 and allowed to leave.

4. Results

We employed a repeated measures design, enabling each subject to serve as her own experimental control. This design, however, obviated the use of covariance to control for systematic between-subject differences. We used subject selection (as described in the Section 3) to help control some differences, and report here variance associated with prior domain knowledge (M = 0.91, SD = 0.08), reading ability (M = 0.40, SD = 0.07), and metacognitive awareness (M = 0.74, SD = 0.11)—three interpersonal factors that have been associated with hypertext-assisted learning (Shapiro & Niederhauser, 2004). Small standard deviations indicate that subjects were fairly similar across these measures.

Results of this study are presented in the following sections: (a) cognitive load, (b) learning performance, and (c) hypertext browsing behavior.

4.1. Cognitive load

A 2 × 5 repeated measures MANOVA was conducted to determine the effect of leads on learners’ cognitive load. Presence of leads (Lead vs. No-lead) served as a within-subject factor, and the five measures of cognitive load: (a) reading time; (b) self-reported mental effort; and Event-Related Desynchronization percentages of (c) alpha; (d) beta, and (e) theta brain wave rhythms were used as dependent measures.

The MANOVA for cognitive load measures was significant (F(5,12) = 58.94, p < 0.01), prompting further analysis through a series of univariate repeated measure ANOVAs. For each of the ensuing ANOVAs, presence of leads served as the independent variable, with each of the cognitive load measures serving as a dependent measure. A main effect was found for reading time (F(1,16) = 5.55, p < 0.05, MSE = 427.63). Subjects spent more time reading in the lead condition than in the no-lead condition (X̄ = 587.23, SD = 116.06 and X̄ = 571.83, SD = 126.20 s, respectively). Main effects were also found for alpha, beta, and theta ERD (F(1,16) = 103.47, p < 0.01, MSE = 7.12; F(1,16) = 35.71, p < 0.01, MSE = 15.34; F(1,16) = 252.56, p < 0.01, MSE = 0.13, respectively). Table 1 shows that mean alpha, beta, and absolute value of theta ERD’s in the no-lead condition was higher than in the lead condition. These findings reveal lower cognitive load in the Lead condition. No other results reached significance (p > 0.08).

4.2. Learning performance

A 2 × 3 repeated measures MANOVA was conducted to determine the effect of leads on subjects’ learning performance.
Presence of leads (Lead vs. No-lead) was used as a within-subjects factor, and the three measures of learning: (a) recall, (b) structural knowledge, and (c) domain knowledge served as dependent measures.

The MANOVA for learning was significant ($F_{(3,16)} = 6.13$, $p < 0.05$), prompting further analysis through a series of univariate repeated measure ANOVAs. For each of the ensuing ANOVAs, presence of leads served as the independent variable, and each of the three learning performance measures served as a dependent variable.

Main effects were found for both structural knowledge and domain knowledge ($F_{(1,16)} = 9.26$, $p < 0.01$, $MSE = 0.10$; and $F_{(1,16)} = 5.79$, $p < 0.05$, $MSE = 0.12$, respectively). Higher means for learning in the Lead condition on structural and domain knowledge measures indicate that leads produced a positive effect on these indices of learning performance (see Table 2). No other results reached significance ($p > 0.2$).

### 4.3. Hypertext browsing behavior

As reported earlier, the reading time analysis showed that subjects spent more time reading the hypertexts that were augmented with leads. Analysis of the screen-capture data revealed that on average subjects spent 6.77 s reading the leads ($SD = 1.47$), based on the first time they accessed the lead. Fourteen subjects only opened the subordinate nodes one time during their initial reading of the text, following the order of link presentation from top to bottom of the main node and then exited from the browser. The remaining six subjects exhibited a different reading behavior. When reading and browsing traditional hypertext without leads, they first read the entire text in the main node, then went back and accessed subordinate nodes nonlinearly. In the lead-augmented hypertext condition, these subjects accessed the leads sequentially, processing the information in the leads one by one, and then returning to the links and opening the linked nodes in the order that they were presented on the screen. Before exiting from the browser, these subjects reviewed the main node, and re-read each of the leads without actually clicking the link to access the subordinate node.

Bivariate Pearson product-moment correlation analysis was used to examine this browsing behavior. A positive relationship was found between subjects’ metacognitive awareness scores and whether they used leads to review content in the subordinate nodes ($r = 0.63$, $p < 0.01$). This finding suggests that subjects with better metacognitive skills tended to use leads as a tool to review information and regulate their cognition in the lead-augmented hypertext.

#### Table 2

Descriptive statistics for measures of learning performance.

<table>
<thead>
<tr>
<th></th>
<th>Structural knowledge</th>
<th>Domain knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No-lead</td>
<td>Lead</td>
</tr>
<tr>
<td><strong>M</strong></td>
<td>0.53</td>
<td>0.63</td>
</tr>
<tr>
<td><strong>SD</strong></td>
<td>0.18</td>
<td>0.23</td>
</tr>
</tbody>
</table>

A battery of Pearson correlation analyses was conducted to determine whether the effects on cognitive load and learning performance were due to the increased reading time in the lead condition. First, the researchers explored the relationship between reading time in the lead condition and the results of each cognitive load and learning performance measure in the lead condition. None of the results reached significance ($r < 0.40$). Another battery of correlation analyses was conducted for reading time in the no-lead condition and each cognitive load and learning performance dependent variable in the no-lead condition, yielding no significant results. No significance was also observed when running Pearson correlation tests for reading time and each of the individual differences variables (i.e., prior knowledge, metacognitive awareness, and reading ability). Non-significant correlations between reading time and results of cognitive load and learning performance measures indicate that increased reading time in the lead condition was not related to the participants’ learning performance scores and cognitive load. A similar use of correlation analyses to compare the utility of several cognitive load measures was reported recently by DeLeeuw and Mayer (2009).
attention during hypertext reading. During these 20-s time periods, brain activity was heightened in the no-lead, traditional hypertext condition, as reflected by uniformly higher alpha, beta, and theta ERD% values. While following links in the no-lead hypertext may have resulted in an interruption of conceptual flow and mental separation of content from two or more nodes, leads appeared to help learners overcome split attention, and use the now-available cognitive resources for more effective conceptual integration of the new content. This conclusion is corroborated by the results of the tests of learning.

Unlike the EEG-based measures, which appeared to be useful for detecting instantaneous cognitive load, self-reported mental effort may serve as an index of overall cognitive load. Overall cognitive load reflects the individual’s judgment of cognitive investment based on the whole task. In the present study, the self-report measure was completed after reading each hypertext. This summative rating of the mental effort invested in reading the entire hypertext was necessary because administrating the self-report instrument every time subjects accessed a link or lead would have disrupted and altered the primary cognitive activity—developing the situation model of the text. Thus, while leads may have reduced split attention and the resulting extraneous load during the 20 s when subjects opened new nodes (according to the EEG data), subjects did not appear to perceive this as a reduction in the overall cognitive investment in reading the entire hypertext.

5.2. Effects of leads relative to structural differentiation of cognitive load

Considering cognitive load theory’s distinction of intrinsic, extraneous, and germane load, it is important to note that, to date, researchers have been unable to advance the theory by using any of the known measurement techniques to differentiate between the three cognitive load components. Intrinsic, extraneous, and germane load are additive in nature, and structurally the sum of contributions of each load type makes up the total load imposed by a learning material or activity. Further, the main distinction between germane load and extraneous load is that while the former is associated with improved cognition and learning, the latter hinders comprehension due to limitations of content presentation. Keeping this distinction in mind, we propose that the contributions of germane and extraneous load can be deduced by analyzing results of cognitive load measures relative to learning performance.

The results of learning assessments used in this study demonstrate better domain and structural understanding of the content in the lead-augmented hypertext condition. Learning from texts with leads allowed subjects to perform better at identifying the meaning of complex learning theory concepts and sorting concepts based on their associations with specific learning theories. It is likely that leads decreased the semantic space between linked nodes and improved the conceptual integration of information, which ultimately had a positive effect on the acquisition of domain and structural knowledge.

Since subjects exhibited better learning performance after reading lead-augmented hypertext, decreased brain activity revealed by the EEG measures in this experimental condition may signify a reduction in extraneous load. This result is consistent with prior research (Chandler & Sweller, 1992), which indicates that split attention results in extraneous load rather than germane or intrinsic load. In the present study, leads were introduced in instructional hypertext to reduce the amount of detrimental search-and-match processes that can cause extraneous cognitive load, and therefore it is likely that learners in the lead-augmented condition acquired more coherent knowledge structures. This interpretation is consistent with the construction integration model (Kintsch, 1988), which posits that the mere presence of links will not aid reading comprehension because links do not help relate text to the situation model. This model further predicts that labeled links (like leads), which indicate the type of information available in the linked node, might support development of the situation model because labels provide a clue to the reader that the linked information is relevant and should be incorporated in the current situation model, or alternatively, that the link leads to a new topic and thus requires development of a new situation model (DeStefano & LeFevre, 2007).

Reading time data revealed that subjects took more time to process hypertext that was augmented with leads. While the time necessary to process the lead (the average of seven seconds) certainly explains that there was more content to read in the lead-augmented condition, another possible explanation is that longer reading times in this condition may indicate increased levels of engagement with the content and greater germane load. If leads reduced the negative effects of split attention and optimized extraneous load during the 20 s of accessing leads and initial processing of the new node, the learners’ cognitive capacity was effectively increased to allow for deeper integration of new information on the germane level after these 20 s expired. More cognitive resources were then available, enabling learners to assimilate or accommodate new concepts with the existing knowledge base and update the current situation model of the text. Thus, it seems likely that node summaries contained in the leads encouraged learners to relate new information to their prior knowledge and allowed activation of relevant knowledge representations from long-term memory, which resulted in increased germane processing and longer reading times for the entire hypertext.

Finally, structural differentiation of cognitive load can inform analysis of the results of self-reports, which showed no effect of leads on cognitive load. To isolate the potential effect of leads, texts were normalized so they were the same level of complexity, and all participants had little prior knowledge of the domain. Lack of significant differences on self-reported mental effort supports that, overall, the four texts were equivalent in terms of conceptual difficulty, supporting the normalization efforts of the educational psychology experts. Hence, from a structural point of view, the lack of differences in cognitive load as reflected by self-reports might actually indicate no differences in intrinsic load. The type of self-report of mental effort measure used in this study seems to rely on the intrinsic difficulty of the learning materials, and is, in fact, a modification of the Bratfisch et al. (1972) scale that was developed to measure perceived task difficulty.

6. Conclusion

Results of this study have led us to argue that single-attribute cognitive load assessment, such as the widely used practice of measuring overall load with self-reports may not be adequate for systematically describing the causes and effects of cognitive load. Instead, cognitive load should be conceptualized as a dynamic process and assessed using a comprehensive analytical framework that integrates measures to target both the temporal dimensions of cognitive load like instantaneous load, peak load, average load, accumulated load, and overall load, and the contributions of structural load including intrinsic, extraneous, and germane load.

Findings build on prior research on the use of node previews and similar tools. Earlier studies reported a positive effect of lead-like features on improving learning in a search task (e.g., Betrancourt & Bissieret, 1998), and a knowledge acquisition task (e.g., Cress & Knabel, 2003; Schweiger, 2001). Our findings showed a similar effect of leads on acquisition of domain and structural knowledge and extended our understanding of this phenomenon.
by using EEG-based measures to reveal decreased brain activity that may be associated with split attention and extraneous load when subjects were accessing new nodes that included leads. These findings suggest that leads appear to be a potentially useful tool for reducing extraneous load caused by split attention, and improving structural and domain learning. Insights gained from this work help us better understand cognitive processes associated with hypertext-assisted learning, and can help guide the development of these kinds of systems.

References


